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SURFACE PROPERTIES IN ELECTRIC DISCHARGE MACHINING

F. Roethel

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16. Abstract

Research on electric discharge machining (EDM) parameters, workpiece surface variables, and flaw structure is summarized, including studies by the author and colleagues. Relations between crater diameter, crater depth, surface roughness, discharge current, ignition delay, discharge pulse width, discharge energy, metal removal rate, metal hardness, applied voltage and cooling rate are explored. The test arrangement and the steel grades tested are described. Types of flaws (inclusions, blisters, notches, porosity, microvoids and shrinkage cavaties), crack depth, thermal conductivity, grain boundary diffusion and succession of phases (retained austenite, hard martensite, soft martensite) and surface layers are dealt with.

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DESIGNATIONS

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d_c	μm	crater diameter
h	μm	crater depth
i_e	A	spark current
$\bar{i}_e$	A	mean spark current
KT	—	carbide hardness
p_e	bar	dielectric pressure
PM	μm	gas bubble depth
t_d	s	delayed ignition time
t_r	s	spark time
t_i	s	pulse time
TV	μm	production effect depth
u_i	V	simple voltage
v_e	cm^3/s	dielectric velocity
V_w	mm^3 min	removal
W_e	Ws	spark energy
δ	μm	crack depth
$\bar{\delta}$	μm	mean crack depth
δ_{max}	μm	greatest crack depth
ν	%	comparative treatment
τ	—	pulse factor

1. Introduction

Among the main parameters which affect the economy of machine part production is tool wear. It has been shown that repeated sharpening or some other way of preparing tools is not as expensive as changing them during the process. Changing a tool on production machinery means a complete loss of time, which can easily be shortened by replacing the tool as soon as possible. Sometimes it is more convenient to change it after a definite period of time. The quality of the surface and the strata immediately under the surface

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*Numbers in margin indicate pagination of foreign text.

affect wear on the tool. This is particularly true of those tools which must withstand high dynamic loads, most often at high temperatures. When a process is automated, tool wear is at the head of the essential elements which must be considered. The first parameter of the surface, with which we define the surface wear, is its topography. Methods for the topographic description have already been described worldwide today. The bases for a mathematical description, however, have already been given [1]. Likewise, surfaces have already been classified according to their characteristic shapes [2]. In producing a surface we do not always gain a typical topographic form which is dependent on the individual manufacturing process, but we also find variations in the layers which are immediately under the surface of the product. A number of researchers and research institutions are busy today investigating surfaces and the strata immediately under them. However, a new research field is composed of so-called "surface integrity research". This research is also being conducted in our country [3]. Studies on surface integrity have a great deal of significance in the electrical removal process of manufacturing. This process belongs to the thermal methods of removal and, therefore, the manufacturing effects penetrate deeply into the surface strata.

2. Surface integrity with the EDM (electrical discharge machining) process

With respect to surface integrity research in all manufacturing processes, researchers worldwide have already decided the area and subject matter to be included in the research by which we technically describe a surface [4]. Surface integrity entails an evaluation of roughness and surface metallurgy. The research has been divided into three qualitative stages, namely according to the number and kinds of data given for the surface. Thus, we recognize:

- minimal research
- standard research, and
- broad research on surface perfection [3,4].

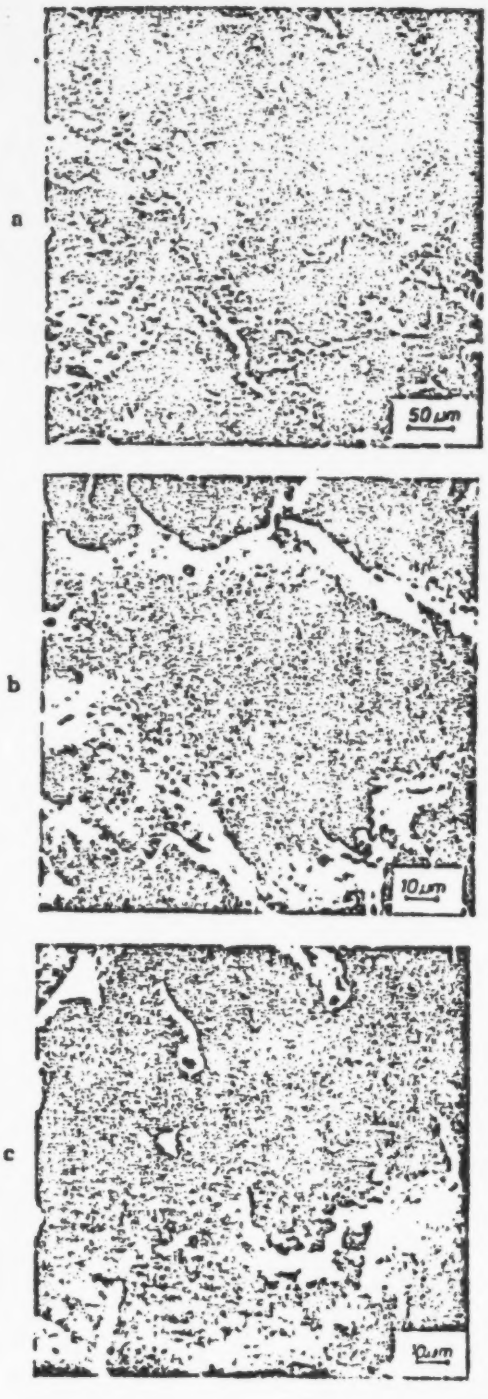

Figure 1. Surface after EDM process

1 Elektroda: E Cu C 20 4 (1)
2 Obdelovanec: HRC 3 (65 HRc)
3 Dielektrik: Erozol Ripo
u_i = 100 V
t_i = 7,5 µs
R_a = 0,3 µm

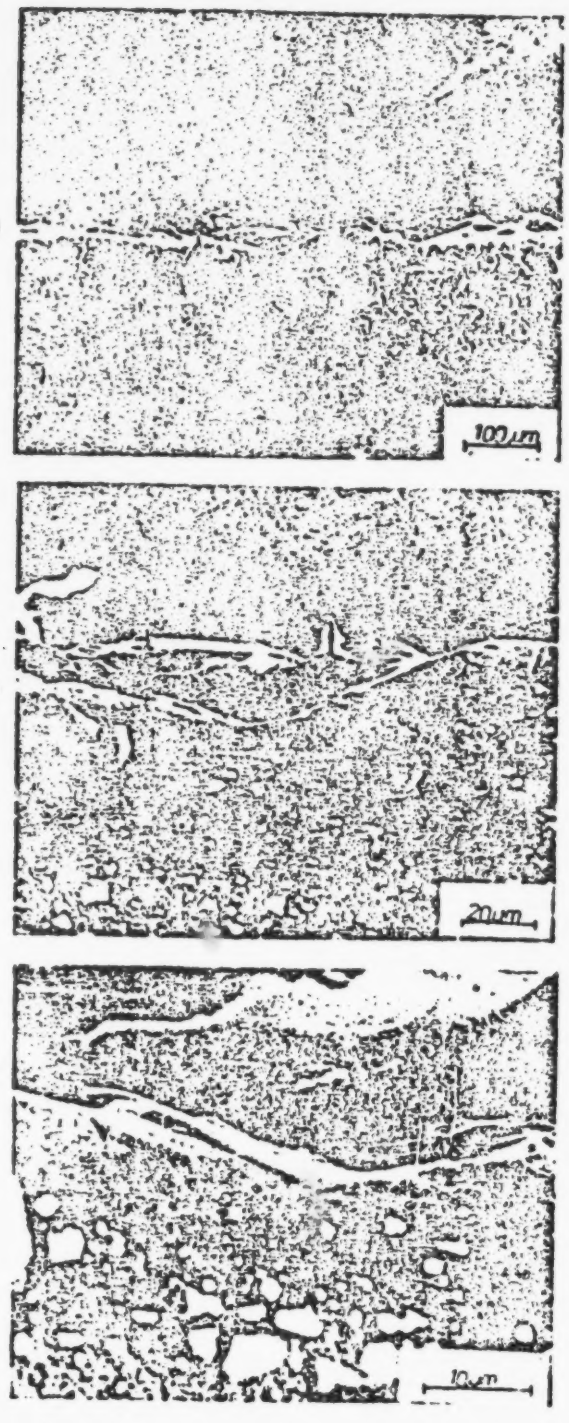

Figure 2. Section of surface after EDM process

1 Elektroda: E Cu C 20 4 (1)
2 Obdelovanec: HRC 3 (65 HRc)
3 Dielektrik: Erozol Ripo
u_i = 100 V
t_i = 7,5 µs

Key: 1--electrode, 2--manufacturer, 3--dielectric

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We assign to minimal research that which provides basic characteristics of a surface layer. Here we consider: The topographic surface, surface macrostructure (macrocracks and variations in macro-etching), microstructure (microcracks), plastic deformation, intercrystalline corrosion, the appearance of bits, notches, abrasion, phase variations, irregularities, dissolved and running layers, selective corrosion and microhardness. This evaluation by itself gives a rather good insight into surface properties. After the evaluation we can easily predict wear on the tool or eventual supplementary treatment.

By research on standard surface integrity, we mean the minimal integrity with sufficient test stability, tests on stress corrosion and on other stresses.

For a very good evaluation of surface properties, we conduct so-called extensive research on surface integrity, where we have to include the data acquired on standard surface integrity from continuous tests and additional mechanical testing, such as tensile tests, toughness tests and ignition, and possibly special tests which are used for special machine elements.

Using EDM processes, foreign researchers have already investigated permanent dynamic hardness and cracks which appear as a result of material fatigue. In this research they have measured the occurrence of fatigue cracks as a function of the magnitude of their bearing strength. To observe the growth of fatigue cracks, they have used optical and ultraviolet measurement technology [4]. The numeric parameters which we have already described [5] affect the electric erosion process.

3. Changes in product and tool surfaces under effect of EDM process /127

In electric erosion processing, a brief low-voltage pulse occurs between the electrodes (tool and workpiece) in the form of electric sparks. The electric sparks cause nonstationary heat

sources of high power on the surface of the electrodes in the vicinity of the spark channel. Some of the heat is used to melt and vaporize metal, while the main heat energy (10^{10} to 10^{11} W mm^2) penetrates the electrodes and heats them to a temperature close to the boiling point of the electrode material [6,7]. On the surface of the workpiece appear nonstationary heat sources which cause numerous changes--primarily plastic and elastic deformation. The electrical parameters of the process have a great effect on the surface properties. Among these are the spark time t_c, the spark current i_e and, as a result, the joint effect of the spark energy W_e. In addition to the electrical parameters, the properties of the tool material and of the workpiece and the properties of the dielectric are important. The effect of the dielectric is not described solely by its physical and chemical properties, but also by the speed and arrangement of flow along the workpiece and its purity.

Under the effect of the hot current, changes appear in the microstructure of the surface. The surface changes to a depth of approximately 10 μm with the lower values of the manufacturing parameters and 400 μm with high values [4]. The surface is covered with craters, with ridges and desposited materials. Today the scanning electron microscope (SEM) makes surface evaluation possible [4]. The surface layer has a structural composition and mechanical properties quite different from those of the original material. The properties are always weaker after the completion of the process. In Figure 1, one can see the effect of electric erosion production on the domestic rapid-cutting steel no. 9682 (BRC 3). Figure 1a shows a photograph of the surface, while Figures 1b and c have enlarged details. Figure 2 presents a section through the treated material with details magnified, where metallurgical changes are already visible. The overall surface topography is dependent on the form of the craters which occur. On the improved surface the differences in the depth and diameter of the occurring craters ($h_i d_c$) must be as small as possible. Research has shown that these differences are somewhere between 0.05 and 0.20. However, theoretical calculations have shown that it is possible for this difference

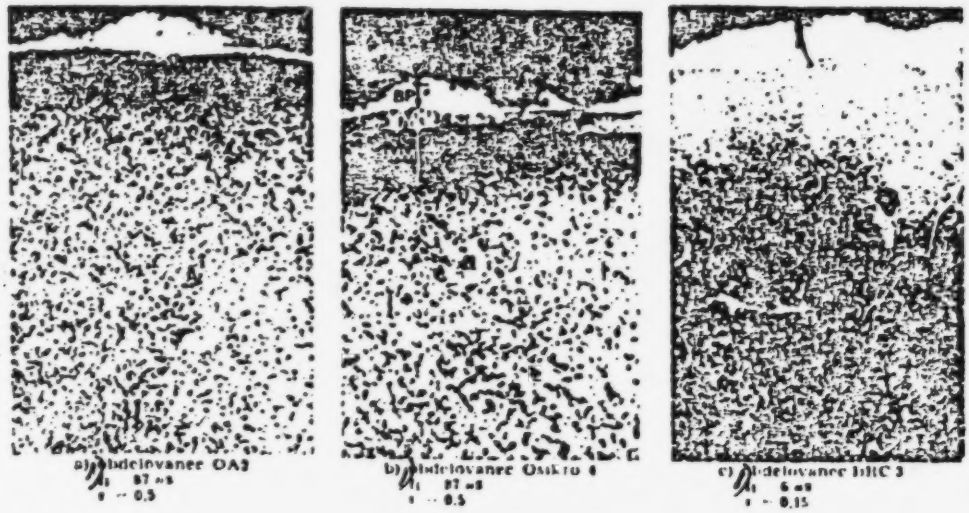

Figure 3. Phase changes in tool steels.

Key: 1--producer

to amount to even 0.50 [7]. With an increase in pulse current (i_e) crater depth (h) is particularly increased. A longer spark time (t_c) increases the diameter (d_c). A shorter pulse time (t_i) and a smaller pulse length improve surface quality. Thus, roughness is reduced with a reduction in the spark flow (i_e). In this case, of course, we must not forget that we get a weaker removal and greater electrode-workpiece wear. A higher heat conductivity in the materials participating in the process leads to a reduction in the difference h/d_c. We get better roughness. Higher dielectric velocity (v_q) has an effect in increasing the ignition delay time (t_d), and we get better roughness, but also poorer removal and greater electrode wear.

The dielectric cools the surface treatment and causes phase variations in the surface stratum. Three different strata form in the surface. The "white" is rehardened material which was heated to a temperature close to the boiling point, and the movement of the dielectric in the gap between the electrodes does not carry it away. We treat most workpieces made of alloyed tool steel with a low critical cooling rate by means of electric erosion. The dielectric causes a rapid cooling rate of heated material because of which

retained austenite appears. Below the white layer appears a second hardened stratum--hard martensite--as a result of the severe heating and slower cooling. Cooling is even slower under the hard martensite stratum. The lower temperatures, which cause a weakening with the appearance of soft martensite (Figure 3), affect this layer. In Figure 3 the hard martensite is lighter, and the soft martensite is darker than the basic material. The time (t_c) and the flow (i_e) of the electric spark primarily affect the thinness of the layer. The thinness of individual strata is not uniform and is accompanied by lesser to greater values which can easily be perceived.

At high temperatures and high pressures, residue from the erosion of removed parts of electrodes and dielectric products diffuse during the process into the surface of the workpiece (white layer). Therefore, the chemical composition of the newly formed white layer is completely different from the basic material. The compositional changes can easily be observed from microanalysis along the planes and lines with a microprobe. Not much research has been conducted as yet in these areas. It is understandable that, as a result of the changes in composition in the strata, a change in microhardness also occurs.

Changes in the surface stratum cause a reduction in the constant dynamic hardness. The occurrence of elastic and plastic stresses has also been researched [7]. Stresses are observed directly from a calculation of the deformation of a roller which is deformed by the removal of thin layers in the cone of influence. The spark energy (W_e) which increases with an increase in pulse width (τ) under constant pulse frequency, has the most effect on other stresses. With an increase in the spark flow (i_e) and the pulse time (t_i), the other strain stresses increase only partially. Other stresses are slightly reduced with a reduction in the energy (W_e) and the pulse factor (τ).

Extreme roughness and cracks in the finished surface have a primary effect on the static properties of workpieces. Materials

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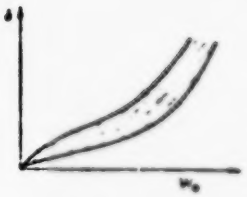


Figure 4. Effect of spark energy W_e on spark depth [11]

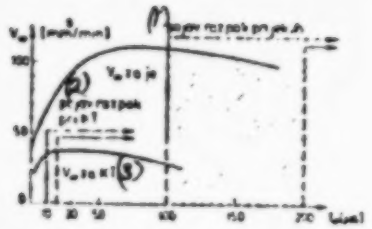


Figure 5. (illegible). 1--crack phenomenon in steels; 2--crack phenomenon in kI; 3--for kI

from the two electrodes, the dielectric and impurities diffuse into the surface layer of the electrode (tool) and workpiece. The diffusion leads to a reduction in strain hardness. Carbon from carbonized electrodes diffuses into the crystalline grain boundaries and causes carbides to arise. In such cases hardness is easily reduced by as much as 80% [4].

/129 missing

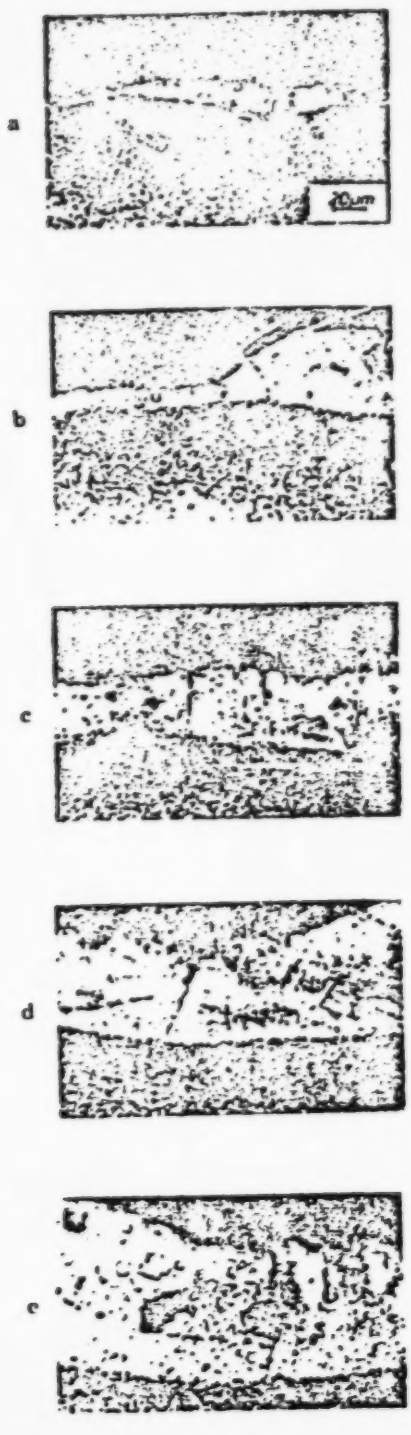
After the treatment we cut some specimens from the flat electrode on the electric erosion machine, prepared disks and then /130 ground them by machine and compared them. We polished them with polishing pastes 3 and 2, and then finally etched them for 15 seconds with 3% nital. The magnitudes changed in the process were the pulse time (t_i) and the spark energy (W_e). The specimens and tools were shaped as is most customary throughout the world today. Thus we can easily compare our results with those of others (Figure 7). The tests were run according to directive VDI 3400.

4.2 Results and their evaluation

The research surfaces and their sections are presented in such a way that the longitudinal (perpendicular to the surface) and transverse microcracks (parallel to the surface) appear in the material. We can easily assume that every electric spark causes microcracks, which run radially in the direction of the crater in the longitudinal and transverse direction of the specimen.

Figure 6. Defects in surface with EDM process (balance of caption illegible)

key: 1--electrode CRM 16



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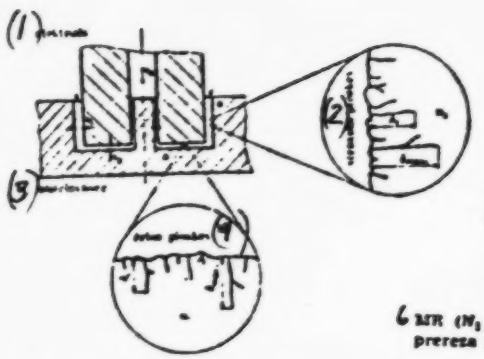

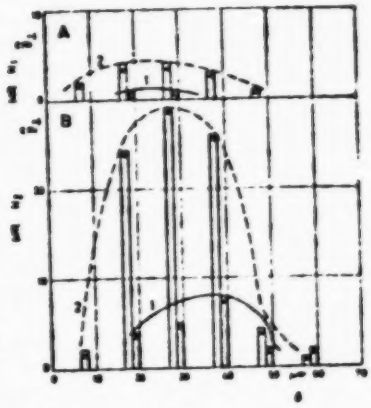

Figure 7. Specimen shape.
A--front plane; B--lateral plane; s_F--front section; s_L--lateral section.
1--electrode; 2--lateral plane; 3--workpiece; 4--front plane

Figure 8. Number of microcracks as a function of (illegible).
A--front plane; B--lateral plane; 1--OSIKRO 4; 2--2-OA 2; 3--electrode; 4--dielectric; 4--aerosol lab
6--MR(N_1 or N_2) mean number of microcracks n in EDM plane section

Most often the cracks arise from small, obscure holes (pores) which occur at places where vaporized material has escaped. In special cases transcrystalline cracks also occur easily [11]. We primarily investigated longitudinal microcracks as a function of the production parameters. We measured them in sections of front and lateral planes and observed their characteristics, size and frequency. We conducted every test three times under all conditions and did not observe any major deviations. In spite of this, to establish data banks it was necessary to run the tests several times in order to get reliable statistical mean values and deviations. In our research we primarily confined ourselves to ascertaining the orientation and course of reciprocal dependence. For the time being foreign authors have not been able either to find reliable data from their measurements, probably because these measurements are very extensive and very expensive. It would be most convenient if (illegible) uniform way, in the form of a cooperative effort, because a single research center with its own financing could not undertake (part of text missing) such an extensive mission. As can be seen from the literature, other authors have also conducted their

measurements only three times. It is probable that some of the world's research institutes have acquired more extensive measurements or better results, but these have probably been made by enterprises interested in keeping these facts as their own industrial secrets.

Microcracks do not have a fixed geometric form and therefore it is most reasonable to classify them according to the number of longitudinal cracks as a function of the depth of front and lateral planes (Figure 8). In the figure we can see a number of cracks of 1 cm on the cracked surface as a function of the size class. In choosing examples of parameters, especially the pulse time (t_i) and (illegible) (i_c), the frequency and depth of the cracks are of great importance. With an increase in pulse time longitudinal microcracks occur more often. Microcrack depth concurs as a function of pulse time [7]. However, the type of microcrack is less dependent on the raw materials than is the number of microcracks. It can easily be seen that the number of microcracks in material is a function of the time and pulse of much greater than in OSIKRO 4 material. The marks in Figure (illegible) and 10 mean the mean measurement value. It has also been observed that pulse current (illegible) increase microcrack depth [11]. The frequency of microcracks in a common origin from the weakening (illegible). In weak aqueous and brittle materials OA 2, microcracks occur more often and in much greater depth than more conductive OSIKRO 4 materials (Figures 8, 9). It is interesting that the mean microcrack depth as a function of pulse time is greater in OSIKRO 4 material (Figure 11).

We can easily see in the diagram in Figure 8 that defects occur more often in the lateral plane (B) and are larger than in the front plane (A). We have not been able to find this in the literature, although it is a phenomenon easy to explain. In studying the EDM process, we noticed that (illegible). We call this the ignition delay time (t_d). It is a well known fact that in a gaseous medium a different section arises than in a fluid medium.

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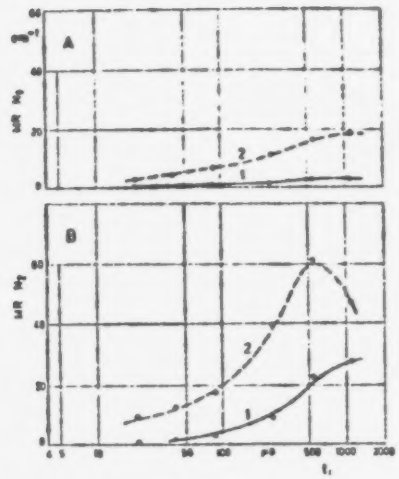

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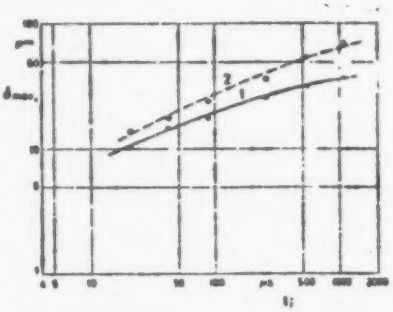
6 MR (N_1 all N_2) — poprečno število mikro razpok na er prereza EDM ploskve

3 Elektroda: E Cu ⌀ 20/4 (+)
4 Dielektrik: 5 Erozol lab

Figure 9. Number of microcracks as a function of pulse time.
1--OSIKRO 4; 2--OA 2; 3--electrode; 4--dielectric; 5--aerosol lab; 6--MR (N_1 or N_2) mean number of microcracks per unit of EDM plane section

u_i = 100 V
i_e = 50 A
A — čelna ploskev
B — stranska ploskev
τ = 0,5
v_w = 0,6 cm³/s
1 — OSIKRO 4
2 — OA 2



3 Elektroda: E Cu ⌀ 20/4 (+)
4 Dielektrik: 5 Erozol lab

Figure 10. Greatest microcrack depth as a function of pulse time t_1
1--OSIKRO 4; 2--OA 2; 3--electrode; 4--dielectric; 5--aerosol lab

u_i = 100 V
i_e = 50 A
τ = 0,5
v_w = 0,6 cm³/s
1 — OSIKRO 4
2 — OA 2

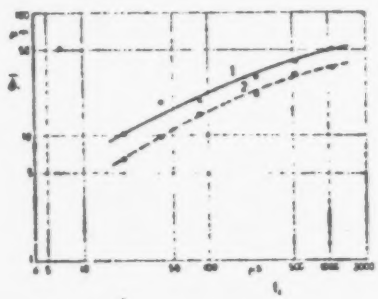


Figure 11. Mean depth of microcracks as a function of pulse time t_1
1--OSIKRO 4; 2--OA2; 3--electrode; 4--dielectric; 5--aerosol lab

u_i = 100 V
i_e = 50 A
1 — OSIKRO 4
2 — OA 2
τ = 0,5
v_w = 0,6 cm³/s

3 Elektroda: E Cu ⌀ 20/4 (+)
4 Dielektrik: 5 Erozol lab

In determining the tension, we work with electrodes in a section which is filled with gas, with electron emission on the cathode. With the flow of electrodes along the gas, molecules ionization occurs, which causes sparking [10]. Because of the reduction of the kinetic energy of electrons, ionization is impossible with heavier fluid molecules. Heuvelman and Hoosten have found that with spark delay there first occurs a trace of a weak electron current which travels from cathode to anode. This electron current heats the fluid until a trace of a vapor bubble occurs, enabling the major sparking. With the spark decay, the dielectric fluid breaks down and tiny particles of electrode material drop off. The dielectric becomes impure, which

leads to a reduction in spark delay. The details of this effect have still not been researched. The eroded particles in the dielectric can increase the density of local flow and the development of new spark channels, which have a lower specific resistance. The result of this is a shortening of the trace delay. As a function of the pulse energy, local concentrations of solid eroded particles and gas bubbles occur along discontinuities. Removed particles are of a random nature and therefore the magnitude of the spark delay in consecutive sparking is very random [8]. In our research, where we rinse the section by pressure through an electrode (Figure 7), the current carries away the particles which have eroded, and the gas bubbles are carried to a vessel through the lateral section. These particles and bubbles enable faster sparking. As a result of this, there is also an increase in the spark energy on the lateral plane because of the lower consumption for channel ionization. This leads to greater effects on the lateral plane than on the front plane. However, this is very significant in practice because tools produced with the EDM process are usually better treated along the lateral plane than along the front plane. Therefore, more attention should be devoted to them in research.

We have tried to uniteour observations in a common diagram for practice (Figure 12). In making the diagram we considered only the mean values of measurement magnitudes and presented the slope of curves in such a way as to illustrate the research of foreign authors. It is obvious that the number of repeated measurements has been reduced, although in consideration of the research of foreign authors on other materials and under different working conditions, we can easily conclude that our results are quite clear and applicable. The figures also present the values for gas bubbles and the depth of strata in the initial phases, which we have not analyzed and treatedin detail in our work.

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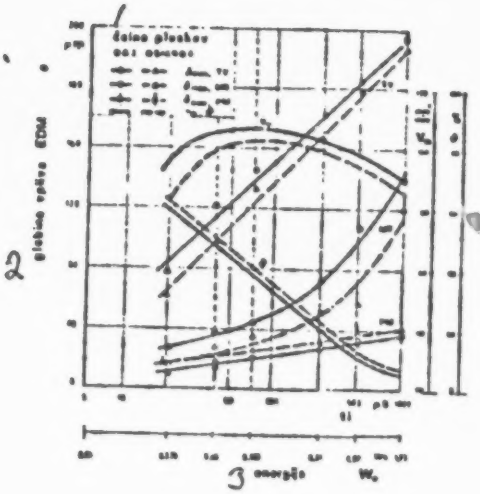

Figure 12. Production of defects as a function of pulse time t_i

Electrode: E Cu C 99.8 (-)
Erozol lab

Dielectric:

u_i = 100 V τ = 0.5
i_k = 50 A v_k = 0.6 cm³/s

PM - gas bubble
MR - microcrack
TV - production effect depth
1-ill.
2-EDM defects 3-energy

5. Conclusion

A great many parameters affect the electric erosion manufacturing process (EDM [electric discharge machining]). Therefore, in selecting electrode material and workpieces, we must deal with future tools very carefully. Tools and products of various materials have already greatly changed the appearance of product quality. What is worse, materials have a higher or lower range of tolerance among standards so that various elements are no longer reliable with respect to their reaction with certain alloyed elements. In treating certain materials, we must carefully select the primary electrical parameters for the generation of properties and the dielectric current. Optimal activity is not only increased removal of material, but less wear and desirable roughness along with mechanical, physical and chemical properties of the surface layer of the material made. These lead to later wear and erosion of the workpiece and should be changed in the tool. We can easily achieve excellent product properties by treatment on more levels, with a reduction in electrodes and changing the parameters for the job. In treatment we presume two phases of work: The greatest possible removal and the best surface formation. In the removal phase, we pay special attention to a refined treatment, with which we try to

avoid any possible defects and changes in the surface.

In this short paper we have tried to introduce technical clarity in connection with the research area which is under development in our country and which we have just begun. With it, we hope that the first results will be applicable for our industry and, at the same time, we thank the Research Society of Slovenia and Boris Kidric Fund for their financing, making possible the work of the research team of"identification of metal materials on the basis of the theory of pulse processes and research on surface integrity as a function of technological procedures" and thus making our work possible.

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